



The Combined Release and Radiation Effects Satellite Program CRRES

A Unique Series of Scientific Experiments

(NASA-TM-104957) THE COMBINED RELEASE AND
RADIATION EFFECTS SATELLITE PROGRAM (CRRES):
A UNIQUE SERIES OF SCIENTIFIC EXPERIMENTS

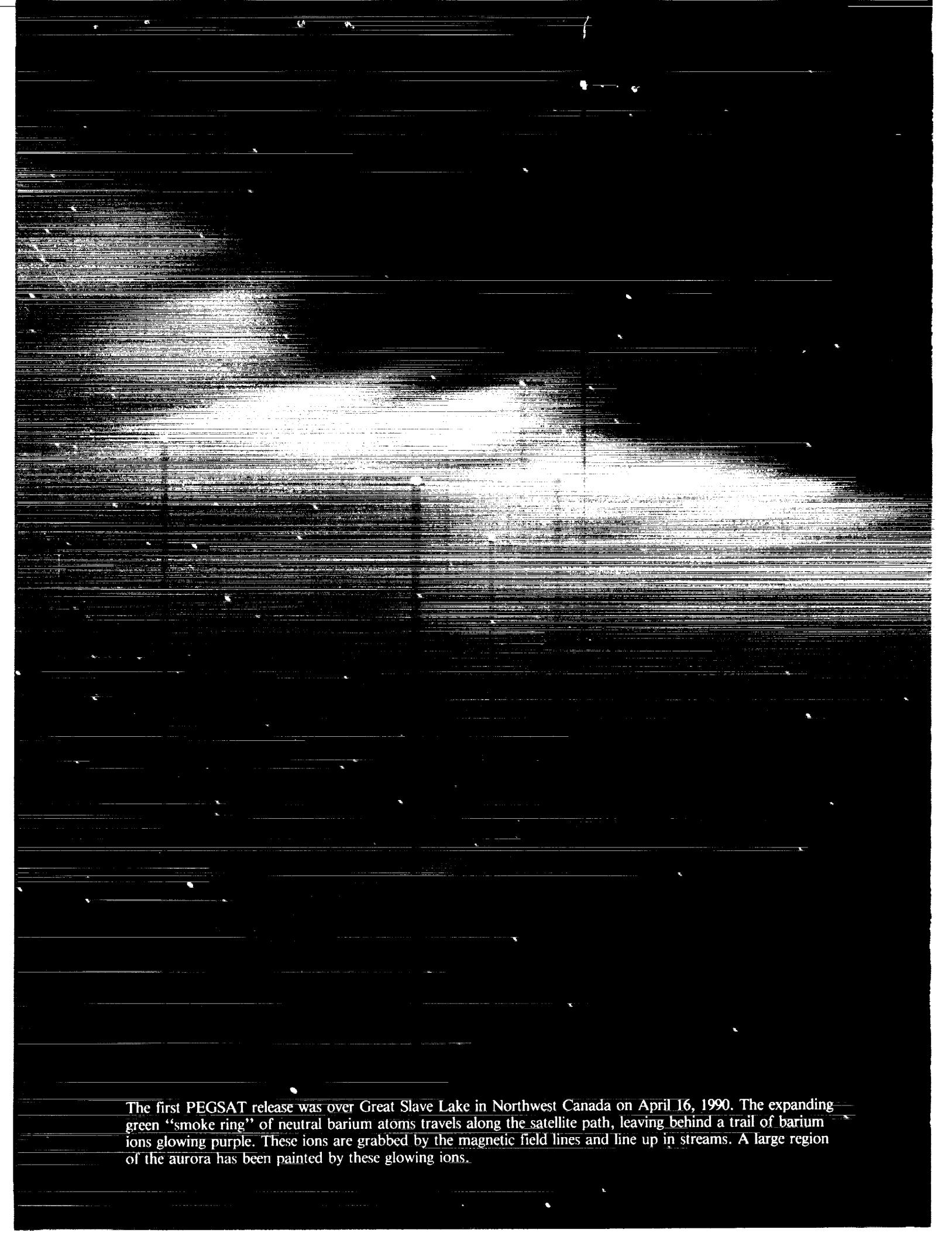
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The first PEGSAT release was over Great Slave Lake in Northwest Canada on April 16, 1990. The expanding green "smoke ring" of neutral barium atoms travels along the satellite path, leaving behind a trail of barium ions glowing purple. These ions are grabbed by the magnetic field lines and line up in streams. A large region of the aurora has been painted by these glowing ions.

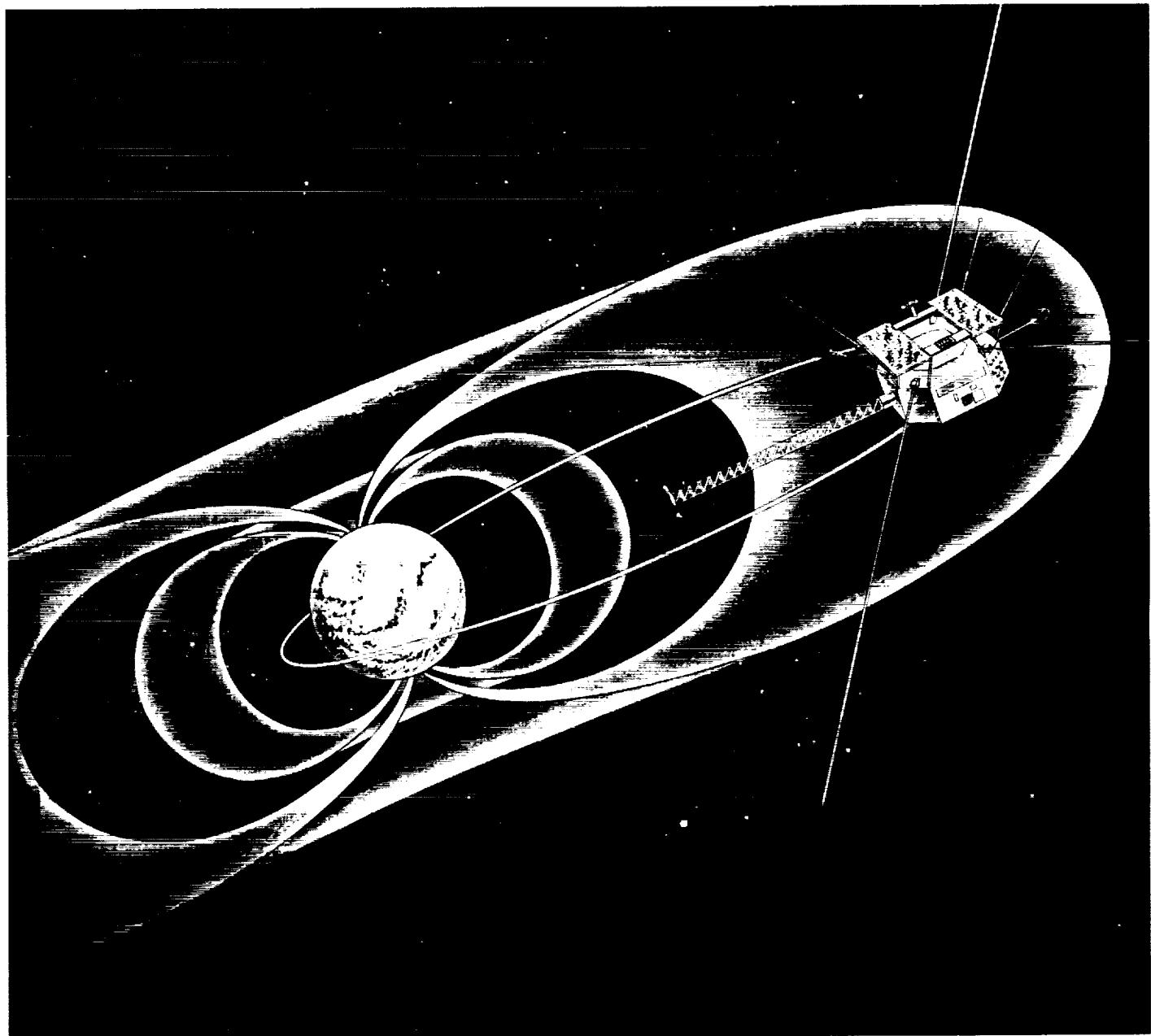
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ORIGINAL CONTAINS
COLOR ILLUSTRATIONS



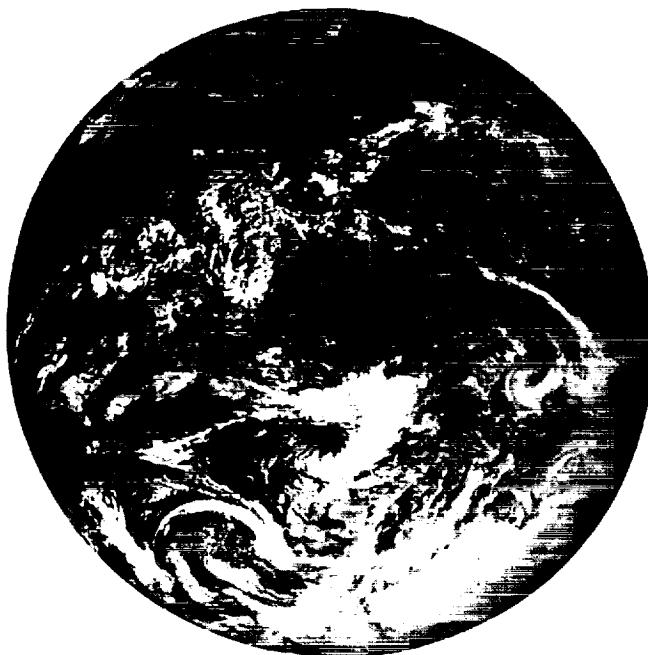


A Depiction of CRR&ES GTO orbit through toroidal Van Allen Radiation Belt, showing Geosynchronous Transfer Orbit (GTO).
350 KM perigee to 35,786 KM apogee.

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The National Aeronautics and Space Administration (NASA) and the Department of Defense have joined in a program to study the space environment which surrounds Earth and the effects of space radiation on modern satellite electronic systems. The COMBINED RELEASE AND RADIATION EFFECTS SATELLITE (CRRES) will carry an array of active experiments including chemical releases and a complement of sophisticated scientific instruments to accomplish these objectives. Other chemical release active experiments will be performed with sub-orbital rocket probes. These chemical releases will "paint" the magnetic and electric fields in Earthspace with clouds of glowing ions. Earthspace will be a laboratory, and the releases will be studied with an extensive network of ground-, aircraft-, and satellite-based diagnostic instruments.

We live in a thin shell of air only 100 miles thick on the surface of planet Earth. The sun provides energy in the form of light and heat, making life possible. Most of what we experience - wind, rain, heat, cold, and life itself - is made possible by the energy from the sun and the fortuitous place of Earth in the solar system. We are not too close, as Venus with its clouds of carbon dioxide and surface temperature of 700 degrees; nor are we too far or a bit too small, as Mars which lost its atmosphere millions of years ago. Above our atmosphere, above the air and clouds, not directly known to our senses, lies an exciting realm of magnetic fields, electric fields, radio waves, and atomic particles that is as important as the air we breathe. This is EARTHSPACE surrounding us with a protecting mantle of magnetic fields that shields us from harmful cosmic radiation.

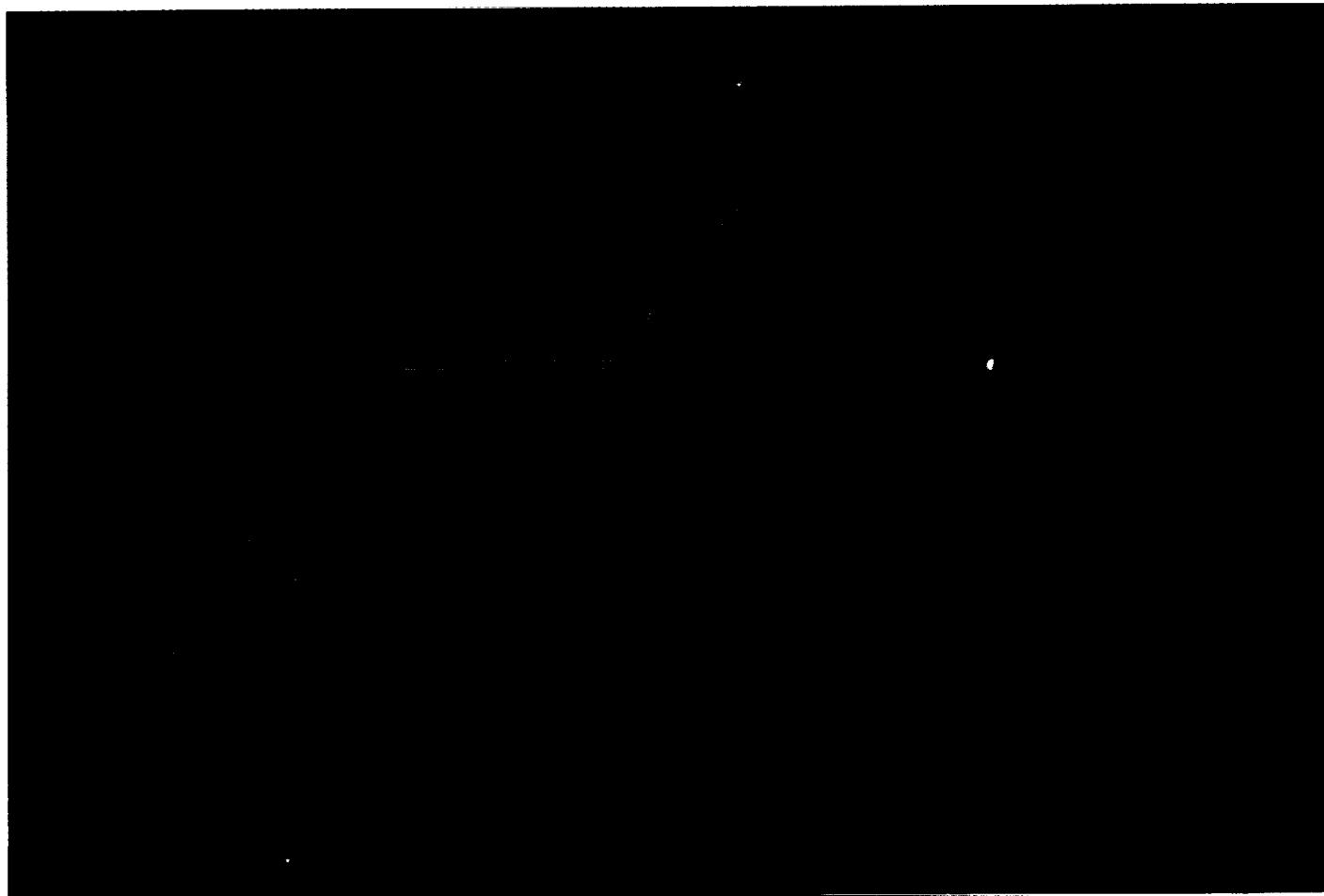


Earth View from Apollo 17 spacecraft, showing Africa and Antarctic ice cap.

The most obvious manifestation of Earthspace around us is the aurora, or the northern and southern Lights. Known to the ancients, these lights in the regions of the Boreal and Austral Poles were first interpreted as being supernatural in origin, and later attempts were made to ascribe scientific causes, such as sunlight reflecting from ice clouds high in the atmosphere.

In the Middle Ages, the Italian scientist Galileo, while looking at the

sun through a telescope for the first time, noticed dark "spots" on the surface that were ever changing. As the sunspots were studied over the years, the number of spots waxed and waned in an eleven-year cycle. Also noted was that the chance of viewing the aurora rose and fell with the number of sunspots. Thus began the realization that the sun "communicated" with the Earth in ways other than light and heat. This was the first real beginning of modern space physics.



Typical blue-green "drapery" aurora borealis, as seen from Ft. Smith, Canada.

How Earthspace Affects Us

Even before the era of direct space exploration with satellites, scientists had begun to perceive that electrically charged atoms flowing outward from the sun collided with the magnetic field of the Earth and played a significant role in creating the Earth's environment. Reception of radio waves over long distances showed the presence of a layer of conducting gas above the atmosphere. At the time, explorations were limited to ground-based instruments, and much of the important data necessary to build even a rudimentary understanding were not available.

The launch of the United States scientific satellite Explorer I came during the International Geophysical Year 1958. This was a time of increased awareness of the importance of magnetism, electric currents, and charged particles surrounding the Earth. The premier scientific discovery of Explorer I was the Van Allen Radiation Belt. This discovery showed that charged atomic particles, electrons and ions, were trapped within the Earth's magnetic field above the atmosphere and immediately began the scientific quest to understand the source of these particles and how they obtained high energies.

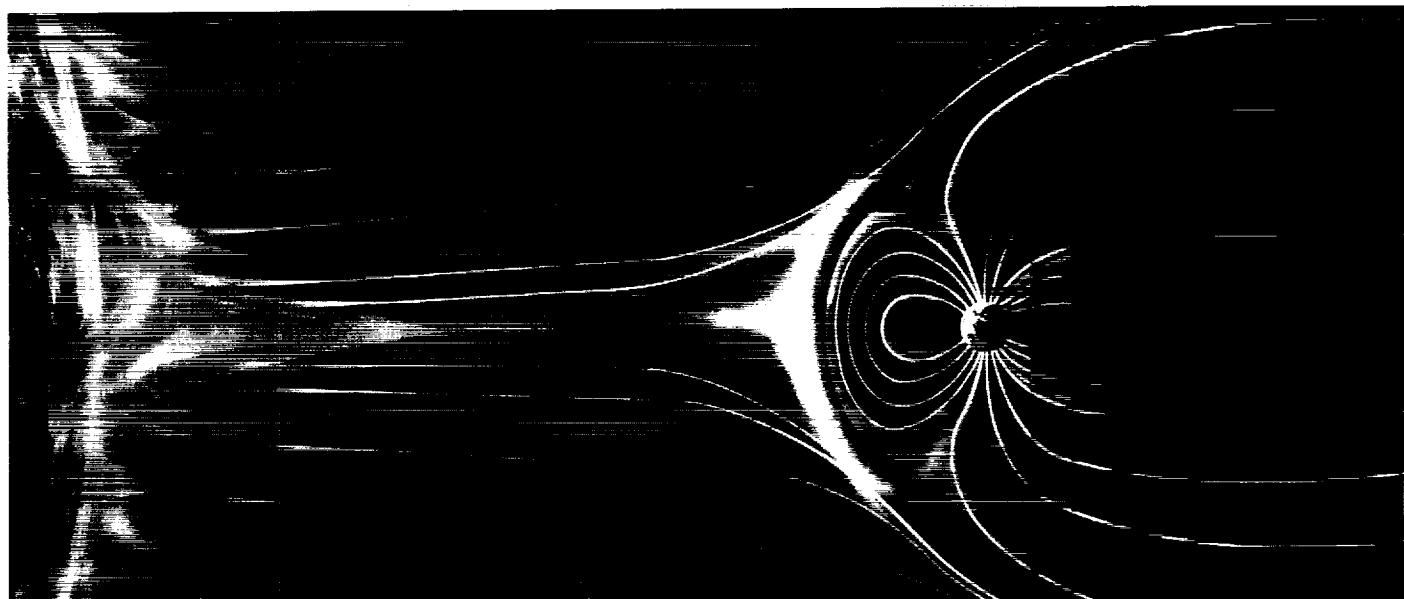
We are familiar with three states of matter: solid, liquid, and gas. Ice, liquid water, and steam are three forms of a substance known to us all. A fourth state of matter exists in space, a state where the atoms are positively charged and share space with free negatively charged electrons. This state of matter can conduct electricity and interact strongly with electric and magnetic fields. We call this state of matter a PLASMA.

Three decades of probing Earthspace with a wide variety of instruments have led to a model of the essential features of the Earth's magnetic field and plasma environment.

This region is known as the magnetosphere. The Earth and its atmosphere seem insignificant in scale compared to the size of the magnetosphere. The Earth holds the dynamo which generates the magnetic field and the atmosphere, which is a source of matter to the magnetosphere. Close to the Earth, the magnetic field looks like the familiar field of a pattern of iron filings around a bar magnet. This is called the dipole field; and on the surface of the Earth, it can be used for navigation with a compass.

Far from the Earth, as the magnetic field weakens, the hot plasma blowing from the sun - called the solar wind - pushes against the magnetic field. The magnetic field is compressed on the side toward the sun and is stretched out downwind to form a long tail. Even though the magnetic field is weak, it is still capable of holding within it masses of plasma with high energies.

Energetic charged particles constantly race along magnetic field lines and smash into the upper atmosphere in the polar regions, causing the beautiful aurora. The magnetosphere is not static. It constantly stores energy, releasing it in sudden surges. These impulsive releases of energy and changes in the magnetosphere and ionosphere are important as they directly affect activities on Earth.



Coupling between the sun and the earth with solar wind, bow shock, polar cusps, radiation belts, and magnetotail.

A static picture only hints at the ever-changing nature of this system. The ultra-violet rays from the sun ionize the upper atmosphere, creating the electrically-conducting ionosphere and a source of plasma for the magnetosphere. The energy from the solar wind enters the magnetosphere ultimately creating high-energy charged particles and large-scale current systems.

Large currents generated in the magnetosphere and ionosphere influence terrestrial power systems and cause disturbances - even blackouts. During periods of geomagnetic storms, the ionosphere is "torn apart" into irregular structures, disrupting long-distance radio communication and distorting signals from satellites.

Need for Active Experiments

We are using space more and more for activities which are now viewed as routine. Communications satellites, weather satellites, and navigation satellites are all part of a global network: and we see their influence each time we turn on our television sets. These marvelous machines must operate in the environment of space: an environment often made hostile by high energy charged particles from the sun and the magnetosphere.

Satellite systems are becoming more sophisticated as a result of advances in microelectronics (more can be accomplished with the same power and weight), but the electronics are also more susceptible to radiation damage. The primary DoD mission on CRRES is to measure the present state of the Earth's space radiation environment, to increase the accuracy of the models of the environment, and to measure the effects of that environment on state-of-the-art microelectronic devices and solar cells.

The majority of space science investigations have been accomplished by measuring the space

environment, either remotely or by instruments placed into space, coupled with applying the equations of chemistry and physics. Unlike a situation in a laboratory, it is not possible to bend the space environment to our will and perform a repeated measurement. The environment constantly changes, and our sensors are rapidly moving on space platforms. Imagine that we could perform a controlled experiment where we actually produced a known perturbation in space and measured the effects. That would be an experiment in the true sense of the word.

The technique of active experiments has been used for many years in space science exploration. Injections of matter, electromagnetic waves, and charged-particle beams have been used with great success to probe our Earthspace. CRRES is studying Earthspace with the technique of chemical releases. This is the injection of specific substances into space environment for the purpose of a tracing, modification experiment, or simulation.

Types of Chemical Releases

One of the most common experiments uses a release of one of a group of elements known as alkaline Earth metals (familiar elements such as sodium, barium, calcium, and lithium). These elements possess two very useful properties: The first is that in the presence of sunlight, electrons are stripped away and atoms become positively charged ions: second, is that most of these elements glow with unique colors when lit up by sunlight, and are visible. In small amounts, these types of chemicals can be used as tracers - painting the magnetic and electric fields with glowing ions. This is the same idea as when smoke is injected into wind tunnels to see the airflow pattern over airplanes; or injecting of radiopaque dyes into the body, so that certain structures will be visible on X-rays. Using larger releases, we can modify the environment with artificial plasmas, and the response of the system to this perturbation can be studied.

Another class of materials acts to decrease the charged particle density by chemical reactions. Common chemicals such as water vapor, hydrogen, and carbon dioxide all act to convert positively charged particles to neutral atoms. A "hole" can be made in the space plasma, which can be a significant perturbation, leading to simulations of natural processes or can modify the ionosphere to accomplish a certain objective.

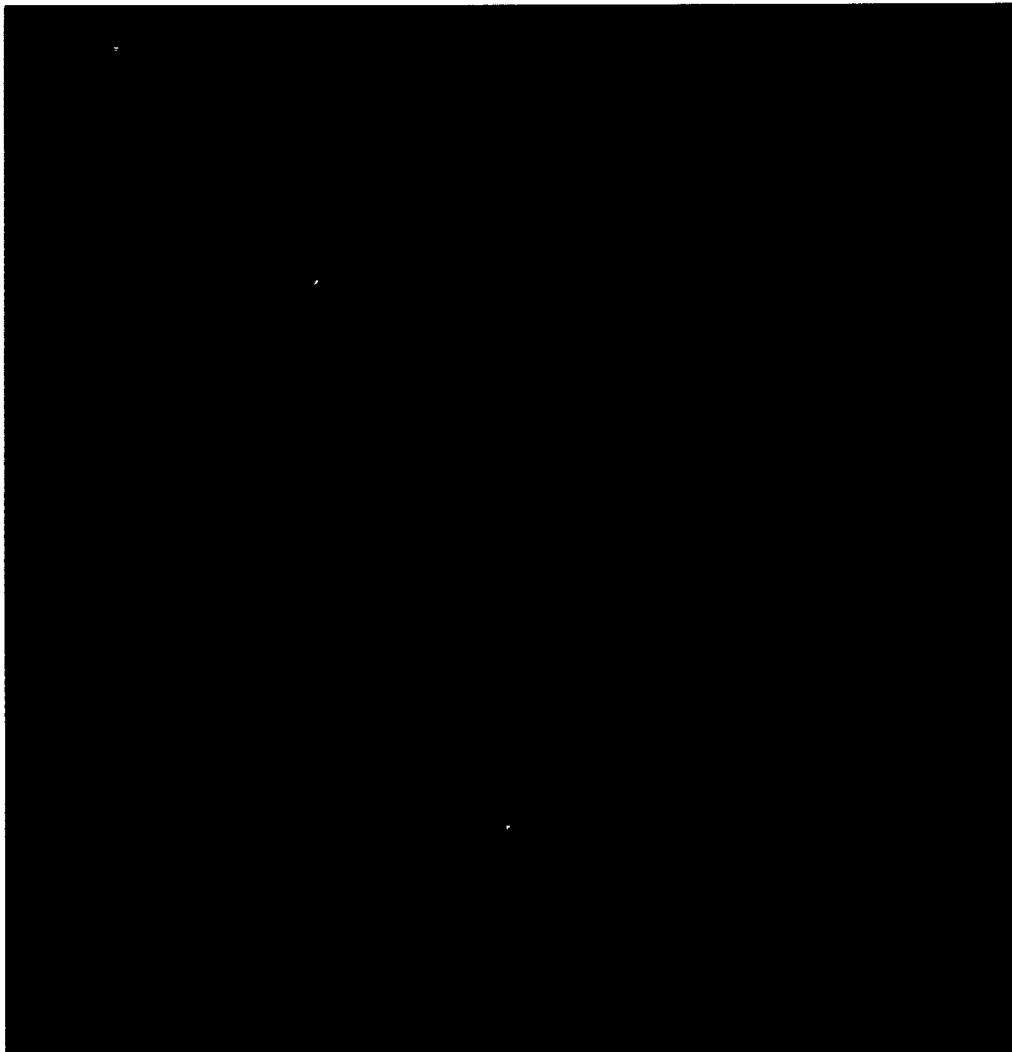
The released chemical must be in vapor form for the effects to occur. Metallic materials are heated to high temperatures, thousands of degrees, in a canister packed with thermite. This thermite burns, and the excess heat energy vaporizes the material and ejects it from the canister into a cloud. In the case of liquids and gases, again it is necessary that the material be ejected in vapor form. External or internal heaters are used to heat the material before release.

The release of substances into the environment does not pose a threat even though some of the materials such as sodium, barium, and lithium are toxic or dangerous when in contact with humans. The chemicals are released in space rather than in the biosphere, and the total amount released will be only 120 pounds. Any chemicals that settled into the biosphere would be dispersed over an area hundreds of miles in size. Calculations show that the potential concentrations in the biosphere are much less than concentrations of the same substances resulting from human activities. (One of the by-products of burning coal is the release of barium which occurs in trace amounts in the coal. The total amount of barium released as a result of burning coal is estimated to be 10,000 tons per year)

A photograph of barium and lithium release clouds shows the unique properties of these materials.

Here the bright red is the emission from a cloud of neutral lithium atoms. Because the atoms are neutral, they are not affected by the electric and magnetic fields and they expand into a sphere.

The purple-colored cloud is the result of barium ions. Barium neutrals become ionized by sunlight in about twenty seconds. A definite streak has formed, and the barium ions are lined up along the magnetic field. The barium has been used as a tracer to "paint a picture" of the magnetic field, which otherwise we could not see.



CRRES test rocket barium and lithium releases, photographed from Duck, N.C., Nov., 1985.

CRRES is not the first mission to conduct chemical releases from a satellite. Earlier missions such as Chemically Active Material Ejected in Orbit (CAMEO) and Active Magnetospheric Particle Tracer Experiment (AMPTE), conducted releases of barium and lithium in the magnetosphere and in the solar wind. AMPTE was a joint program of the United States, the Federal Republic of Germany, Great Britain, and Argentina. It was designed to trace particle motion over large distances of

Earthspace and to simulate natural phenomena.

The photograph of a comet is really an artificial comet created by a release of barium in the solar wind.

This is a "false color" rendering, with the intensity of the measured light represented by the color. Blue represents the dimmest light and white the brightest. The resemblance to an actual comet with a coma and the curved tail of ions is remarkable. It illustrates the power of the chemical

THE ARTIFICIAL COMET
DEC 27, 1984 MPE



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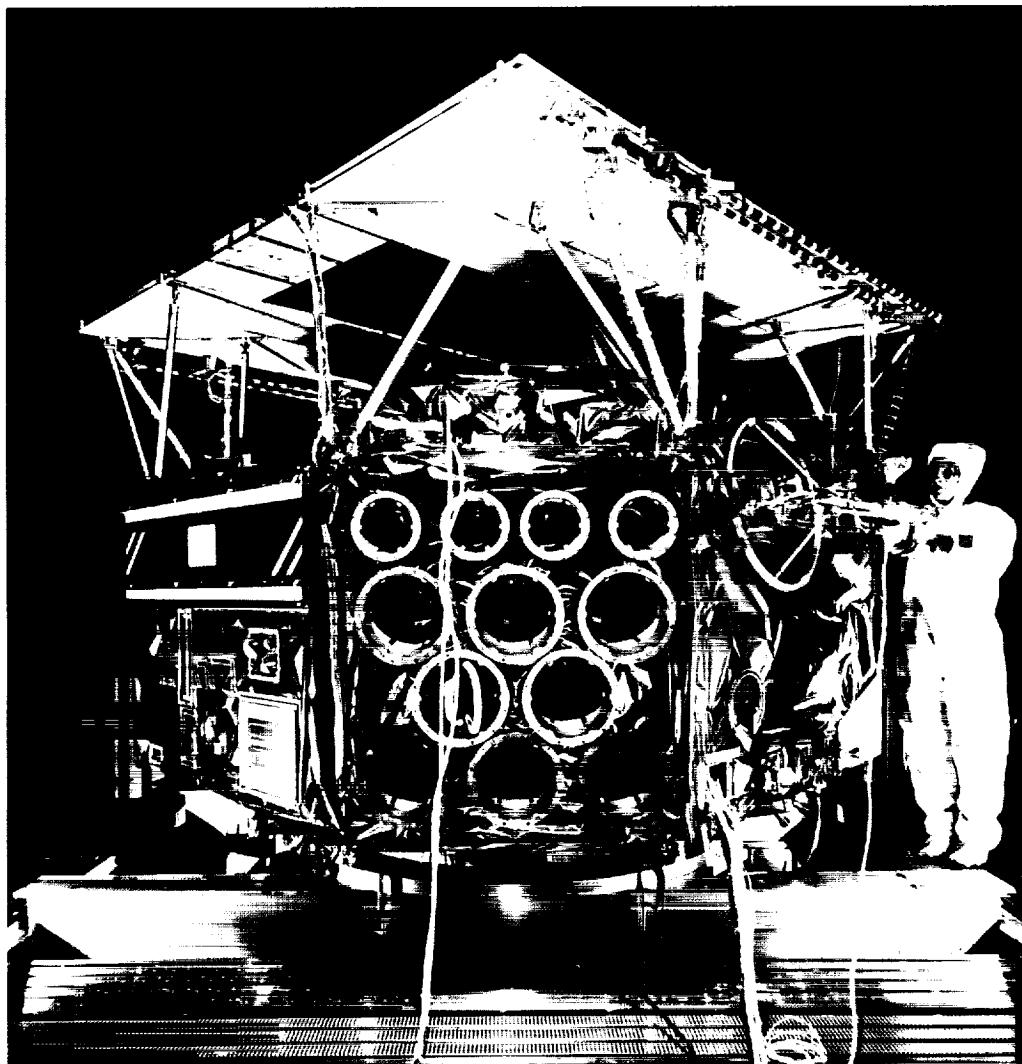
Low-light TV image of AMPTE artificial comet 4.4 min, after BA + plasma injection at 17.2 Re (Earth radii) with tail oriented along solar wind flow direction.

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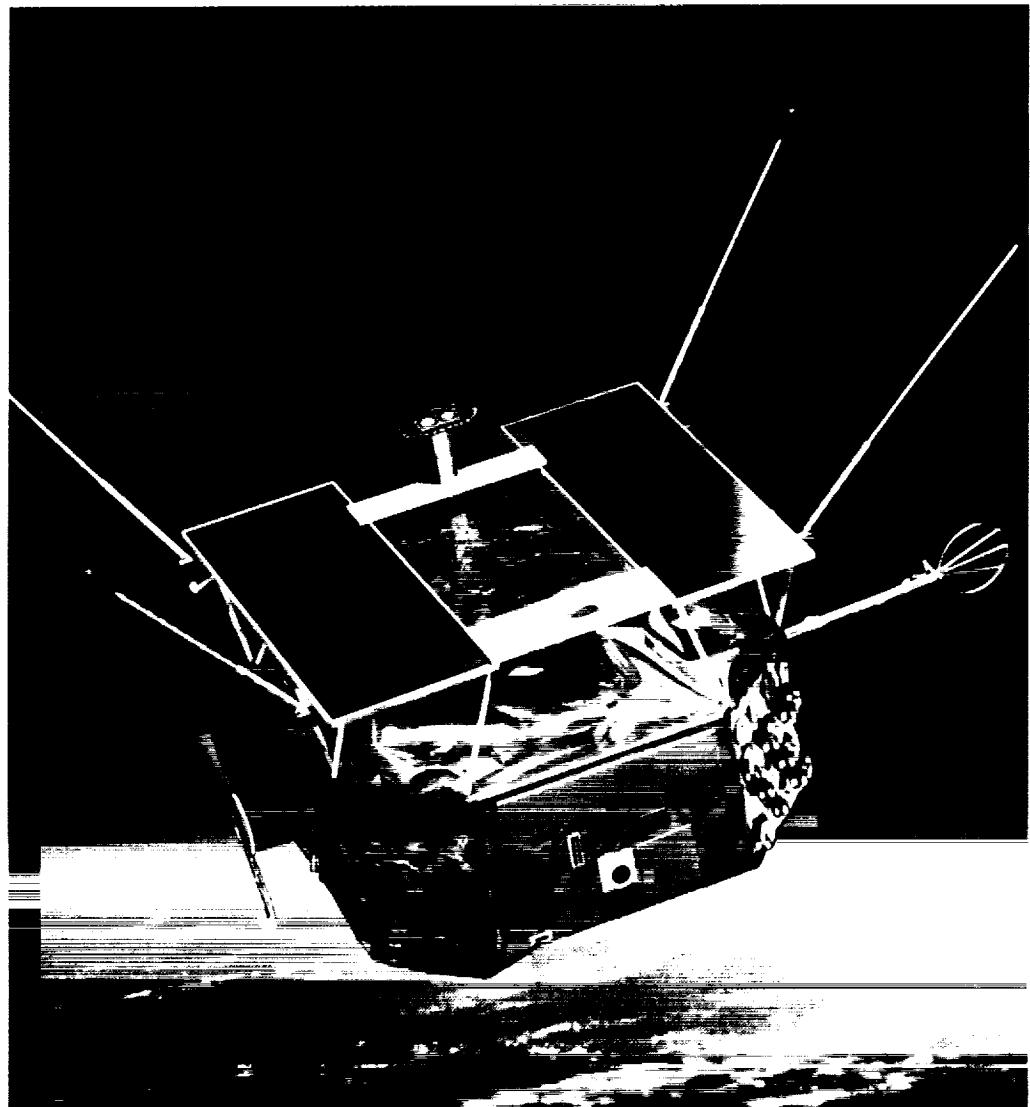
release technique used to study our solar system.

A satellite carrier of chemical releases starts the chemical cloud at its orbital velocity. At first, the released cloud is moving at the same speed as the satellite through space, and the atoms and ions of the release have a large amount of kinetic energy (or energy of motion). The CRRES Program

will make good use of this in conducting a series of unique experiments in the ionosphere. Other experiments will take advantage of the highly elliptical orbit of CRRES, with altitude varying between 350 kilometers and 34,000 kilometers, to reach to the outer regions of the magnetosphere for experiments studying high-energy radiation.



CRRES undergoing testing in "clean-room"-at Ball Space Systems Division, Boulder, CO.



Typical flight configuration of CRRES showing booms extended and magnetic field loop antenna. (Note canister ejection ports at right).

The artist's conception of CRRES in orbit shows the bays holding the chemical canisters, the solar panels for electric power, and the long booms and antennas which are a part of the scientific sensor package. The orbit of the satellite will be known to a high degree of accuracy, and the scientific investigator will determine the exact point for a chemical release

experiment to occur. Twenty-five minutes prior to the actual release, the canisters are ejected from the spacecraft by springs; and at the instant of ignition, the canisters are 3 kilometers or more away from the spacecraft. Releasing at a distance protects the delicate spacecraft surfaces and instruments.

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Pegasus rocket mated with NASA B-52 aircraft.

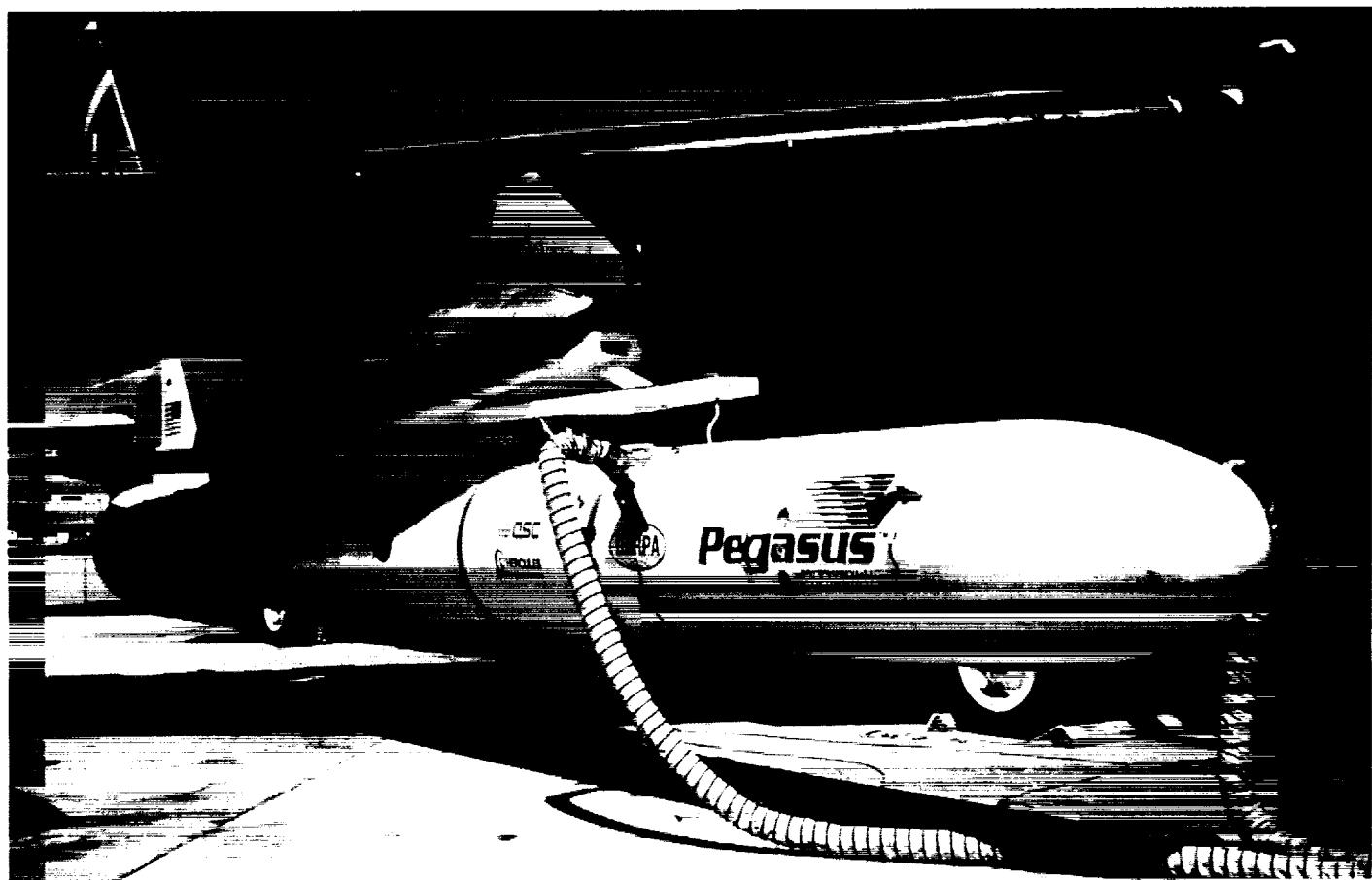
The CRRES Program has taken a "hitchhiker" ride on the first launch of the PEGASUS rocket, to make two barium releases over Canada. The PEGASUS is a private launch vehicle development. On its first

flight, PEGASUS carried an experimental DoD satellite and NASA chemical canisters. The releases, in April 1990 were used to study the electric structure of the space regions in the aurora.

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On April 5, 1990, as part of the CRRES Program, the first flight of the Pegasus rocket carried into orbit the PEGSAT spacecraft which included two canisters (similar to

those on CRRES) to make releases over Northern Canada. The Pegasus releases were used to study the electric structure of the space regions in the aurora.

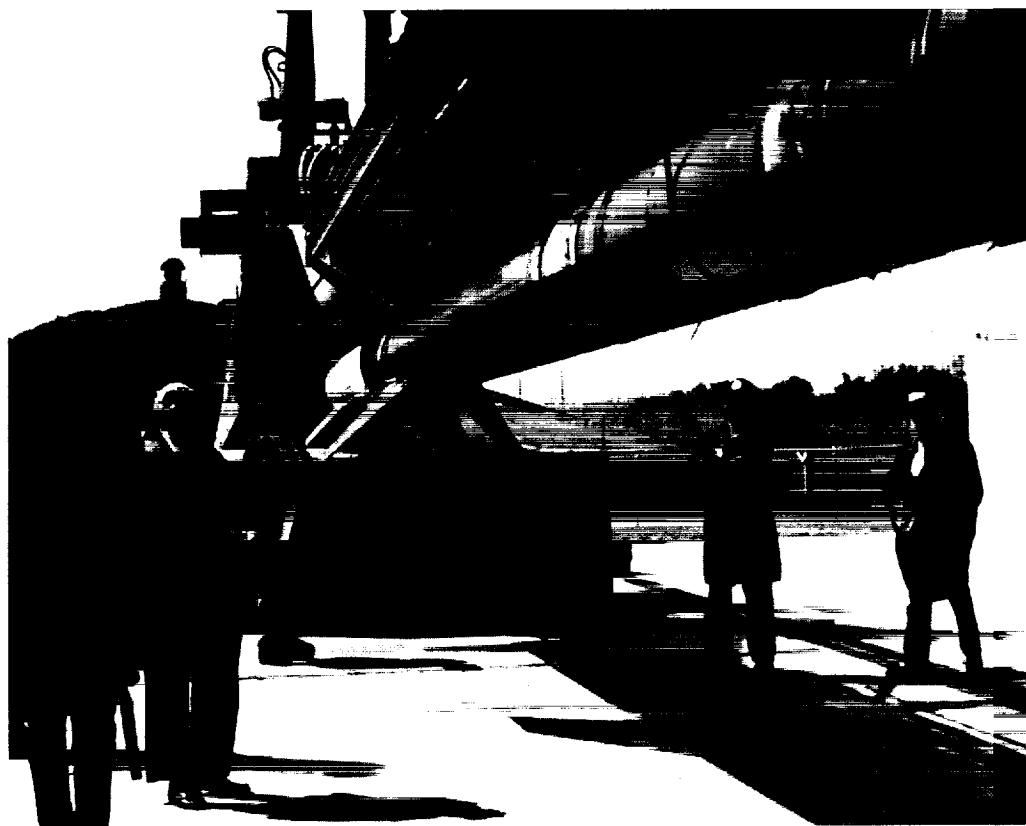


Pegasus rocket before ignition.

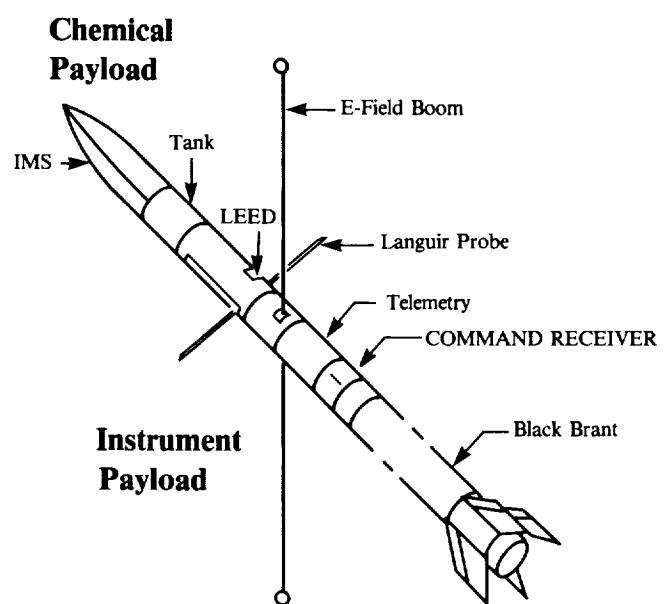
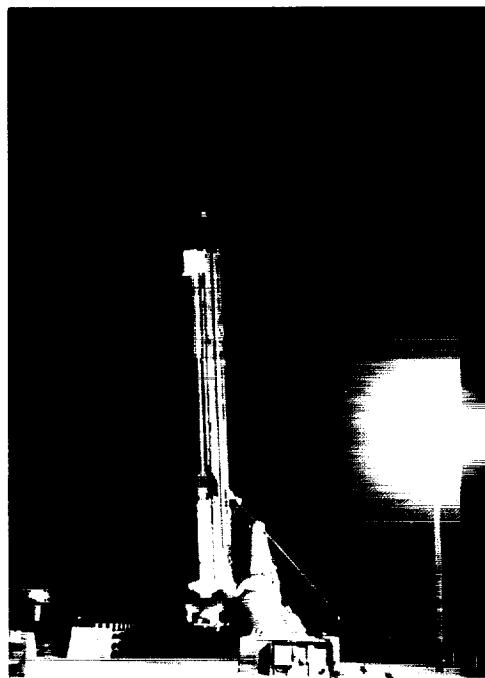
A sounding rocket is a versatile chemical release carrier if orbital velocity is not required.

This Terrier-Black Brant was used to conduct a program of two vapor releases to create ionospheric density depletions, or "holes." A sounding rocket can carry large amounts of a chemical to create a large-scale perturbation and, in general, can be

more precisely targeted in space and time. For example, some of the CRRES Program experiments require targeting a release to within a circle 40 kilometers in diameter at an altitude of 250 kilometers within a time period of 10 minutes. Such accuracy is routine with a sounding rocket, but is difficult with a non-maneuverable satellite.



Inspection of Black Brant IX, Wallops Flight Facility, VA.



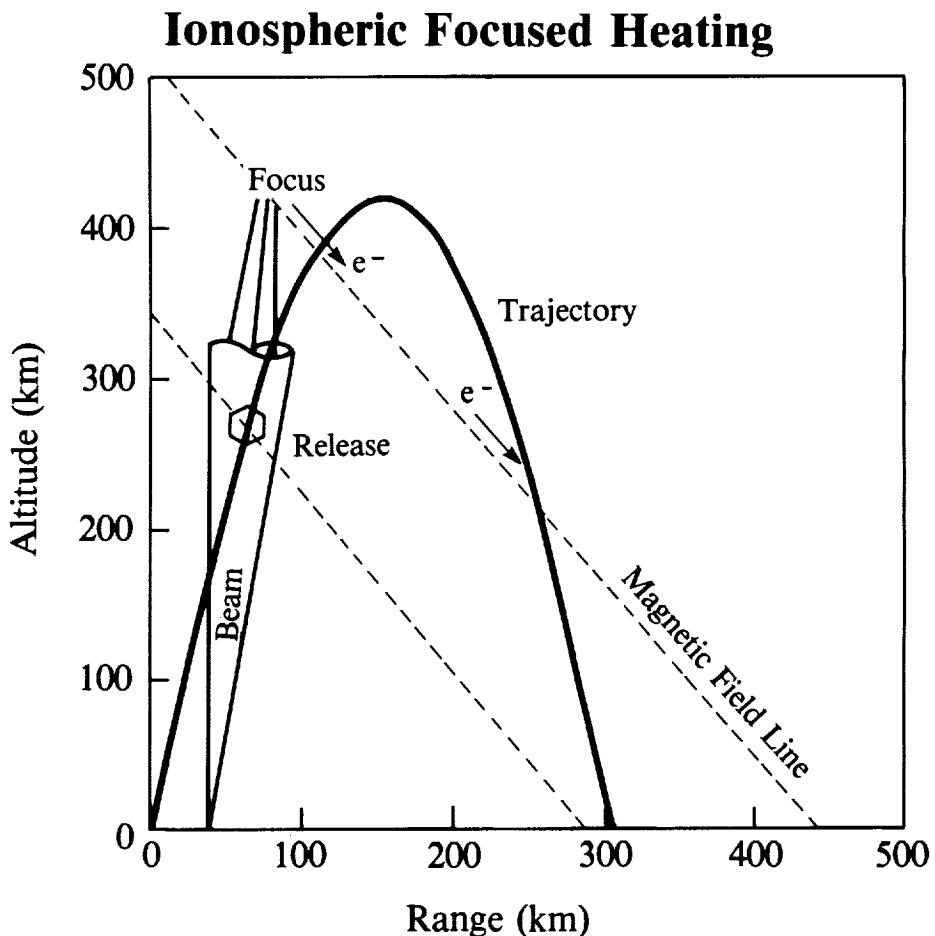
Sounding rocket instrumentation and diagnostics profile.

Typical launch configuration of sounding rocket on launcher, ready for midnight launch.

CRRES Program Schedule

The CRRES Program will span a period of more than one year. The PEGSAT releases occurred during April 1990. The CRRES Spacecraft was launched in July 1990. The first releases from the CRRES Spacecraft will occur in September 1990, with a pair of releases in the vicinity of American Samoa in the South Pacific. These releases will test a theory of Critical Velocity Ionization, a process leading to an anomalously large amount of ionization as a gas moves at high speed across the magnetic field in the ionosphere.

As the apogee (high point) of the CRRES orbit moves into the midnight region of the Earth's magnetosphere, artificial plasmas (ion clouds) will be injected to learn how resident particle populations react to this intrusion. "Dumping" of trapped particles in the Radiation Belt is expected to occur. Particles are perturbed out of their stable trajectories in the magnetic field, rush along the magnetic field to collide with the upper atmosphere, and create an artificial aurora. July and August 1990, will see a series of sounding rocket releases of

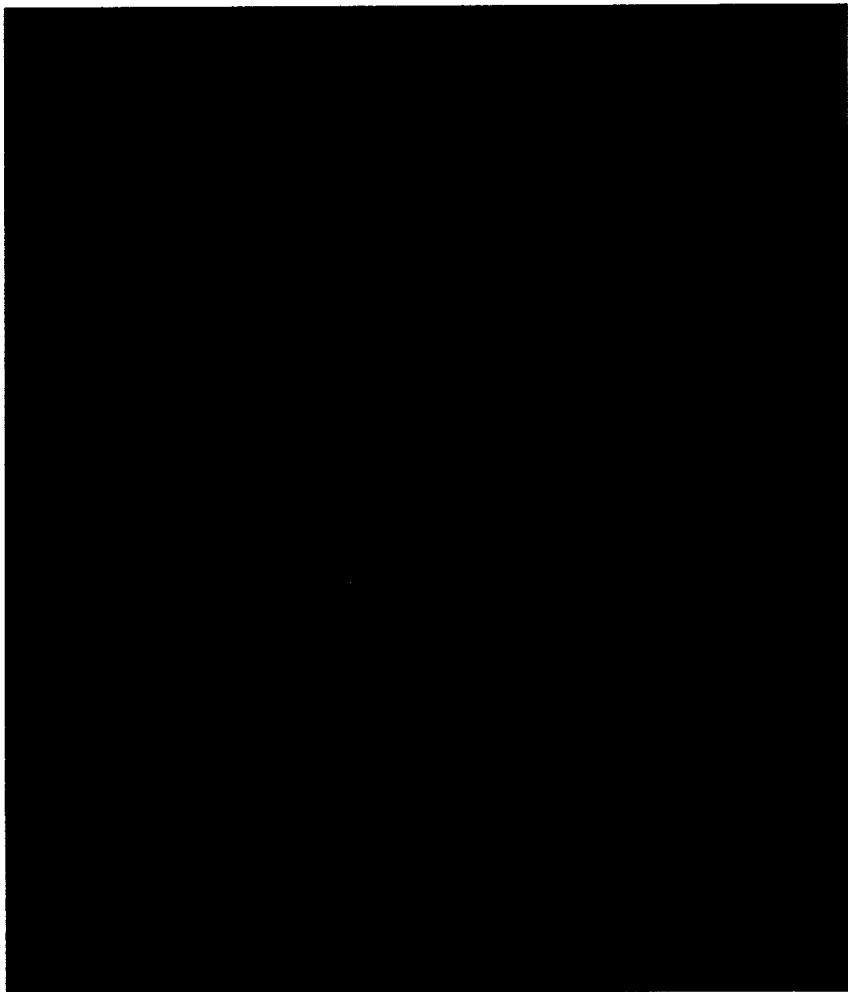


an ionospheric depletion vapor from Kwajalein Atoll, Marshall Islands.

These releases are to study the formation of irregularities in the ionosphere-a phenomenon known as Spread-F.

The CRRES Program will conclude with an ambitious campaign of satellite and sounding rocket releases in the area of the Caribbean in June and July 1991.

This campaign will feature releases easily visible from the Southeastern United States in the predawn hours. The objectives include studying the motions of ions for long distances along the line of force of the magnetic field and studying the response of the ionosphere to specific, controlled perturbations. "Arches of glowing ions" along the magnetic field will be made with an injection at high velocity from CRRES and will be visible to high-sensitivity cameras over a very large area of the northern and southern hemispheres. In a perturbation experiment, the release of a depletion vapor will create a "hole." This will focus the beam of a high-powered radio transmitter. Scientists will be able to study how the ionosphere reacts to high levels of energy input, which happens during a major solar flare.

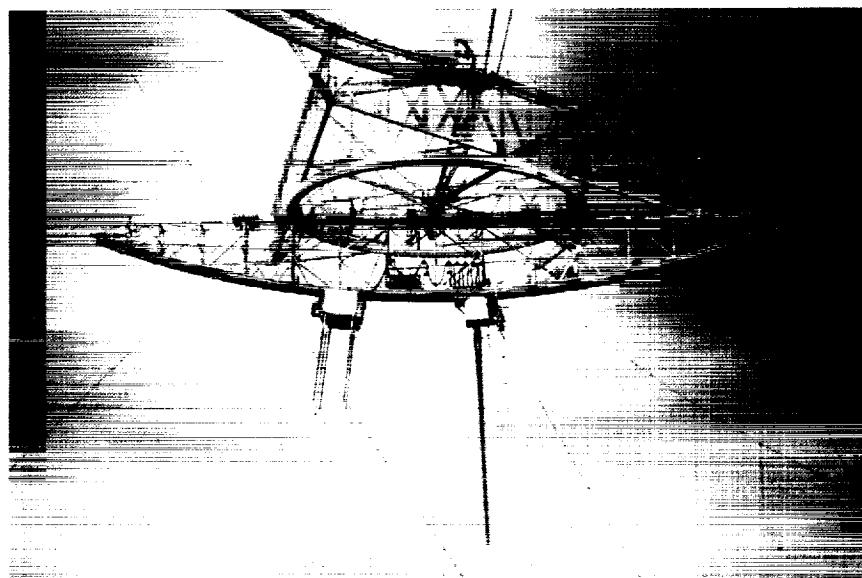


Lithium release. (Taken 2 min. after release)

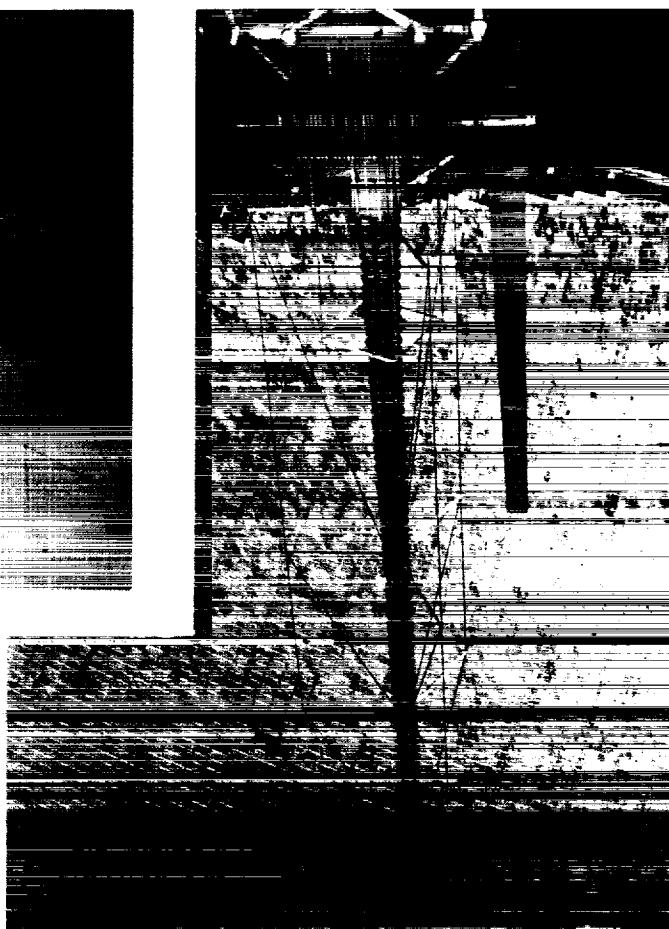
International Support and Coordinated Studies

The CRRES Program is international in scope with participation by scientists from the United States, Puerto Rico, Canada, Germany, Argentina and the Soviet Union. Optical and radio observatories will be located on the Marshall Islands, on Fiji and American Samoa in the South Pacific, in Canada, on Martinique, Anguilla, Aruba, Dominica, and Guadeloupe in the Caribbean, and in Argentina, Chile and Ecuador. Multiple sites are necessary in order to measure accurately the locations of the releases by triangulation.

The radar facilities at Arecibo, Puerto Rico; Kwajalein, Marshall Islands; and Millstone Hill, Massachusetts; will be used as primary diagnostic tools. These radars transmit powerful pulses of radio energy into the ionosphere and analyze the weak returns from the electrically-charged particles there. The amount and speeds of the ionospheric particles and how they are changed by a chemical release perturbation can be measured with high precision using these radars.



Approximate 100' long main receiving antenna and carriage house over 1000' diameter reflector, consisting of 40,000 adjustable aluminum panels. (Arecibo Observatory, Puerto Rico.)



Cameras carried aloft in aircraft will be operated to guard against loss of data from locally bad weather. One such aircraft, a Boeing 707 operated by the Argentine National Commission for Space Research, will provide all-important optical data from the southern end of the ion jets moving along the magnetic field lines. This and other special research aircraft from NASA, the DoD and Aeromet Inc. will contain cameras, gyroscope platforms to stabilize the images, precise navigation systems, and sophisticated computer-controlled pointing systems to aim the cameras at the right point in the sky.

The science instruments on CRRES will be important to the chemical release mission. They will be able to measure important details of the space environment. In some cases their data will be vital to making the decision whether or not to do a release experiment. The state of the ionosphere during all low altitude releases will be known from measurements by the Low Altitude Satellite Studies of Ionospheric Irregularities (LASSII) Experiment. Other charged particle and wave detectors from the DoD experiments will diagnose the state of the magnetosphere prior to the high altitude releases.



Boeing 707 Airborne Observatory. (Argentine Space Agency.)

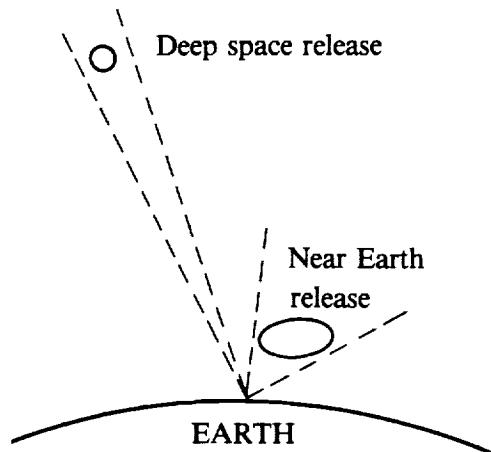
Photographing Chemical Releases

The chemical releases of the CRRES Program, particularly those using barium and lithium, will be visible to the human eye and can be photographed with photographic equipment already owned by the serious amateur. The high-altitude releases in January-February 1991 will be visible over the entire Western Hemisphere; and the Caribbean releases in June-July 1991 will be visible from the entire Caribbean, northern South America, and a significant portion of the southeastern United States. This encompasses two broad categories of chemical releases: those near Earth at less than 1500 kilometers altitude (the Caribbean releases); and those in deep space, greater than 1500 kilometers altitude. The types of equipment required to photograph these two types of releases are quite different.

Near-Earth chemical release photography is considerably easier and requires minimal photographic equipment. All that is needed is a camera with a fast lens and an adjustable shutter with a "T" or "B" setting for taking time exposures. Fast film, a tripod, and a cable release complete the ensemble.

To obtain good photographs of deep space releases, fast long focal length systems are required to obtain good photographs of deep space releases; and clock drives are desirable to compensate for the Earth's rotation. The optical systems can be either fast telephoto lenses (very expensive) or astronomical telescopes (less expensive).

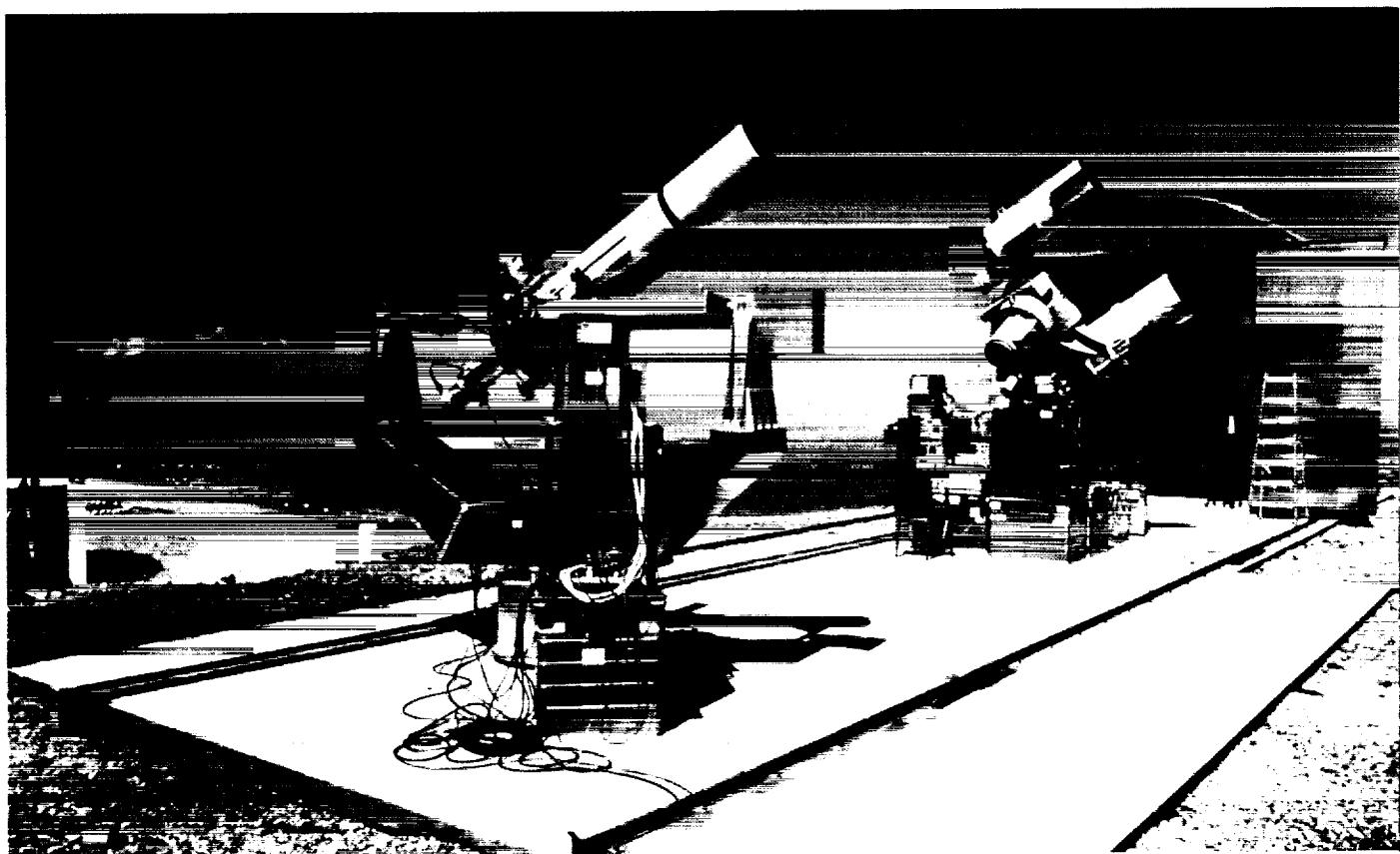
In either type of instrument the speed of the system is very important and should not be slower than F 4.0. The field of view for deep space releases should ideally be in the range 4-8 degrees, and long focal length lenses are not needed or desirable.



Chemical release photography logistics. Near-Earth is close to the 350 KM perigee. Deep-space altitudes can exceed 6 RE (Earth radii)

A rough approximation of the brightest parts of a chemical release cloud are contained within a cloud 100 kilometers in diameter. At 500 kilometers distance, typical of a near-Earth release, this cloud subtends 6 degrees of arc. For a 35 mm camera, a lens in the range 50-70 mm is a good match. Deep space releases will subtend angles down to perhaps 0.5 degrees, but pointing uncertainties and lens speed dictate a FOV of 4-8 degrees as mentioned above corresponding to a lens of 150-200 mm.

When compared to daytime photographic subjects, chemical releases are faint, diffuse objects. Photography of chemical releases is similar to photography of the aurora borealis. Fast lenses and fast films are the primary requirement, but the techniques are by no means difficult. The photograph of the red lithium cloud and the purple barium cloud shown earlier was taken with a 35 mm camera, 50 mm lens, at a slant range of 600 kilometers.

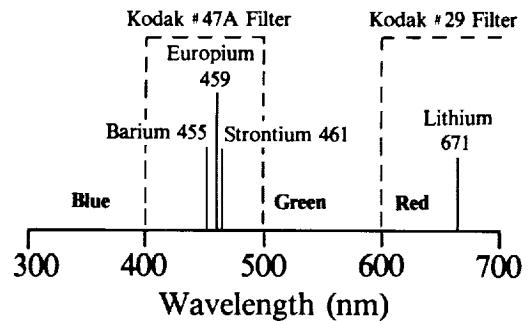


Observation Station at El Leoncito University of San Juan, Argentina at the Cordillera de los Andes.

Many fast films are available for low-light level photography. For color photographs, transparency film is desirable for many reasons. Many of the fastest films are available in transparency film only. High resolution is not needed for chemical release photography, and hence small format film pushed one or two stops is more than adequate.

Scientists studying chemical releases use a large variety of instruments, including optical instruments. As a result, most releases will be accomplished under conditions of darkest skies, no moon and solar depression angles greater than at least 12, and preferably 18 degrees. For the best results, a dark sky site far from artificial lights is very desirable, but becoming increasingly hard to find. If light pollution is a problem, filters may be used to isolate the color of the chemical release being photographed, and thus improve the signal-to-noise ratio. The accompanying figure shows the positions of the resonance lines of common chemical release substances and the filters required.

The value of a chemical release photograph to a scientific study is significantly enhanced with a few



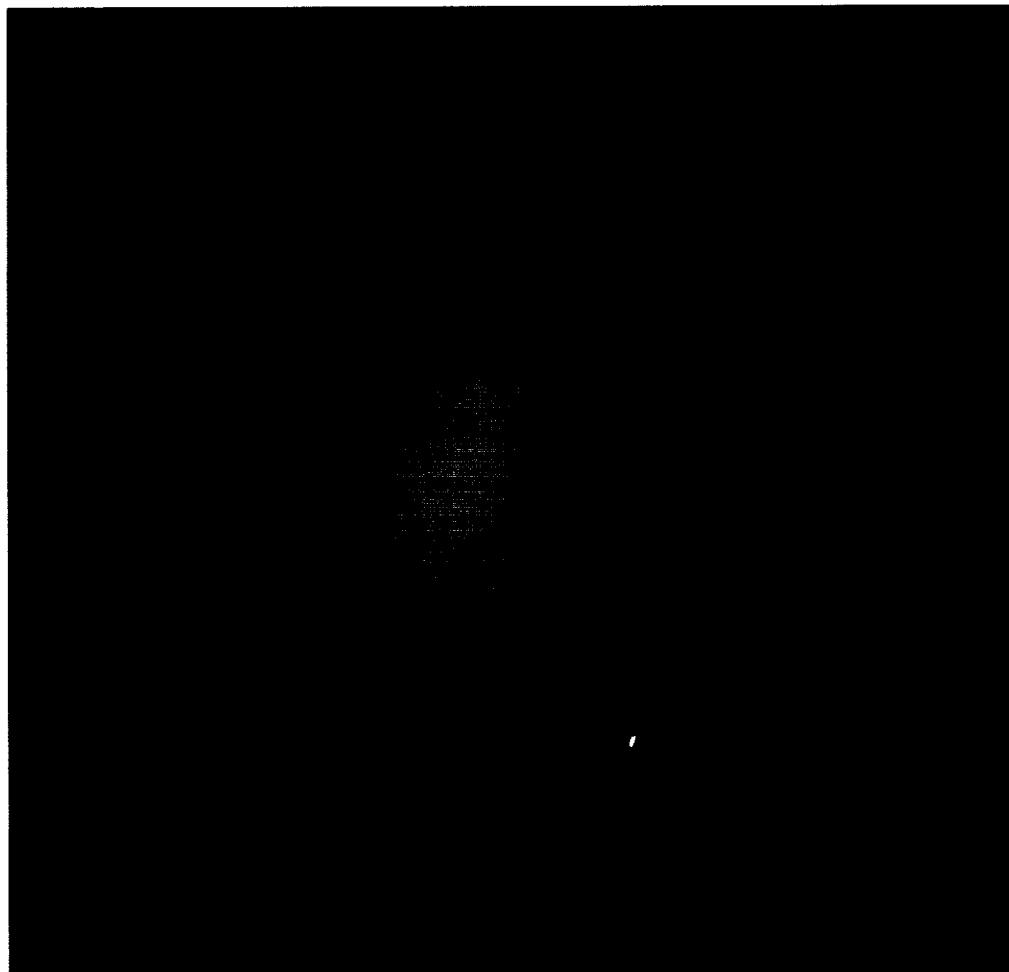
Chemical release photography filters.

simple measurements. Obviously the time of the photograph is crucial, and either a receiver capable of tuning standard time signals such as WWV, WWVH, or CHU; or a good watch recently set to a time standard is essential. Of course, the operator must remember to log the time of each frame or post-release times with a stopwatch. The latitude and longitude of the observing location is important, and this can be determined to sufficient accuracy with USC & GS topographic maps or sectional aeronautical charts. Approximate values of the elevation and azimuth (be sure to state whether relative to true, or magnetic north) are useful, but exact pointing information comes from the star field in the photograph. Chemical releases are also interesting to radio amateurs and professionals studying HF and VHF propagation and scatter. A chemical release acts like a meteor trail of enhanced ion density, but with much longer

duration. In another sense, the effects are like a small-scale Sporadic-E region. The chemical release scientist will be studying some of the release effects with HF bi-static paths, VHF coherent scatter radars operating near 50 and 137 mhz, and with satellite signals passing through the ion clouds to Earth-based receivers.

NASA will make available the time and coordinates (latitude, longitude, altitude) of a release through public media such as astronomy magazines and bulletin transmissions. There are a number of software packages that allow the observer to calculate look angles in azimuth, and elevation or right ascension and declination.

How Will the Amateur Observer Know Where to Look?



Barium release. Payload launched by Taurus Nike Tomahawk from Wallops Flight Facility, VA. Taken from Duck, N.C. using a 305 mm, F2.5 lens, with Kodak Ektachrome ASA 1600. (5 sec. after release)

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CRRES as a Program

CRRES is a joint program of the National Aeronautics and Space Administration and the United States Air Force Space Systems Division. The Space Physics Division of the Office of Space Science and Applications, NASA Headquarters, Washington, D.C. 20546 is responsible for the chemical release program. The Space Systems Division of the USAF is responsible for the DoD experiment program. The CRRES Satellite and scientific campaign is managed by the CRRES Project Office, FA21, NASA Marshall Space Flight Center, Huntsville, Alabama, 35812. CRRES sounding rockets are under the management and technical direction of Wallops Flight Facility/NASA Goddard Space Flight Center. The PEGSAT spacecraft was developed by NASA Goddard Space Flight Center as a joint program of NASA and the DoD Defense Advanced Research Projects Agency (DARPA). The prime contractor for the CRRES Spacecraft is Ball Space Systems Division of Boulder, Colorado; and the chemical canisters are the responsibility of the Franklin Research Center and General Sciences Corporation of Norristown and Souderton, Pennsylvania. The launch vehicle for CRRES is the Atlas-Centaur, developed by General Dynamics Corporation. The Pegasus launch vehicle was developed by Orbital Sciences Corporation (OSC) Headquartered in Fairfax, Virginia and Hercules Aerospace Company. Coordination and documentation of the Investigators Working Group is the responsibility of the University of Alabama in Huntsville's Research Institute.

The Space Physics Community was shocked and saddened by the tragic and untimely death of Dr. Stanley D. Shawhan on June 21, 1990. Stan was the Director of the Space Physics Division at NASA Headquarters. His vision and determination was in large measure responsible for this chemical release science program continuing forward despite several setbacks. More than that, his gentle prodding and unfailing good humor challenged us to pause from looking through our individual knotholes and to instead view the larger prize of research in Earthspace for the benefit of all. Stan was one of the world's true gentlemen, and he will be sorely missed. This brochure is dedicated to his memory.

David L. Reasoner
June 25, 1990

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